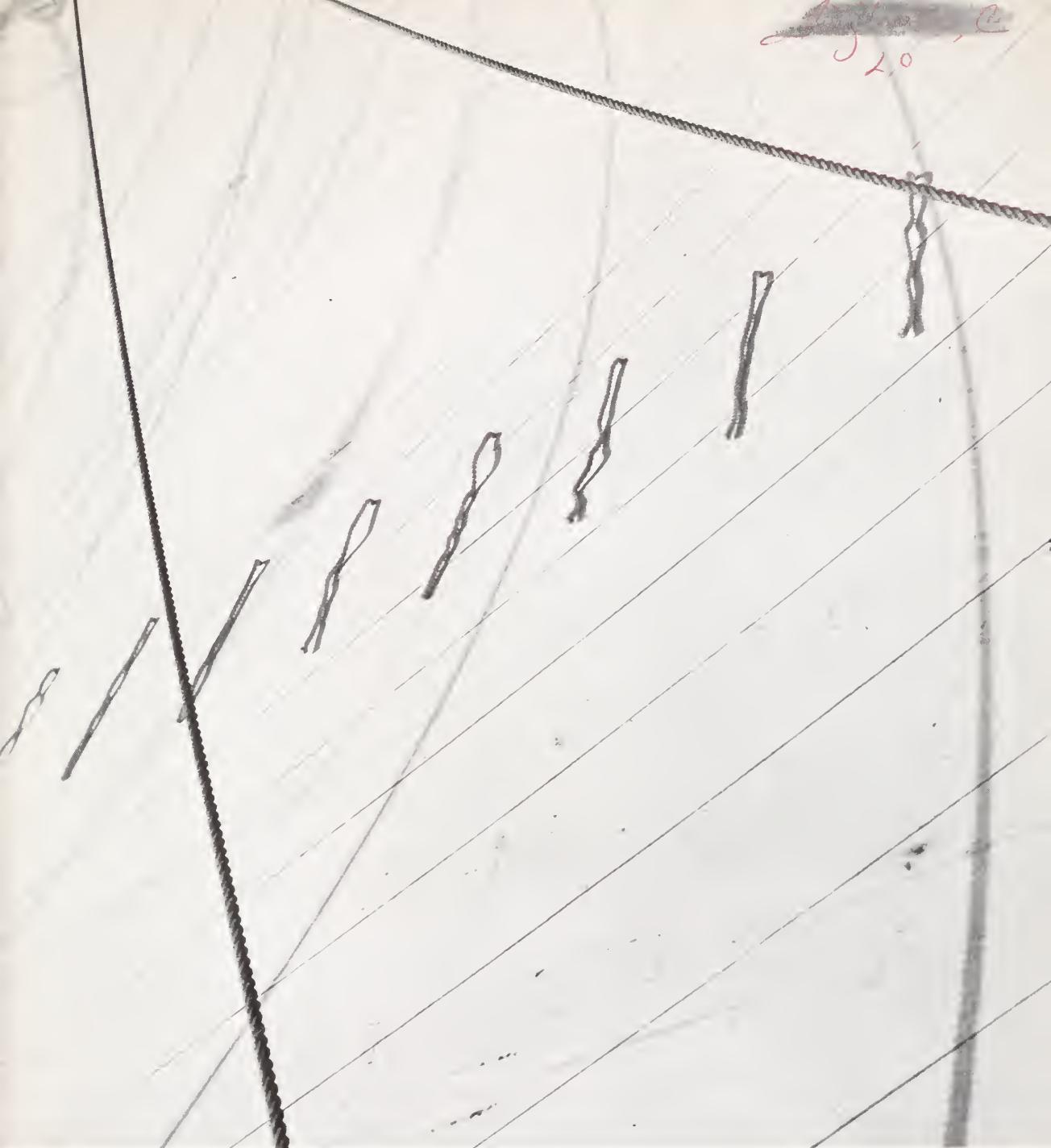


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VOL. XIII, NO. 1 NOVEMBER 1966

# OCEANUS

## *ON THE COVER—*



## **S**HE has sailed away!

**T**HE 'Atlantis' left Woods Hole on November 11th to continue her career, but under the Argentinian flag.

May her coming years be as successful as her thirty years of hard work for our Institution.

On the cover: Her mainsail, reef points, lazy jacks and shadows of the rigging. Photos: j.h.

**EDITOR: JAN HAHN**

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Vol. XIII, No. 1, Nov. 1966

# OCEANUS<sup>TM</sup>

THE WOODS HOLE OCEANOGRAPHIC INSTITUTION  
Woods Hole, Massachusetts

Paul M. Fye, President and Director

IT is interesting to recall that only twenty years ago it appeared as if oceanography at Woods Hole would have to shrink back to its 1930-1940 level of activity. But we have increased in size and in scientific output ever since. Now, the year 1966 may be called the year that oceanography came of age.

In June, the President signed the "Marine Resources and Development Act" while the "National Sea Grant College and Program Act" passed in October. The U.S. Navy gave Adm. Odale Waters the imposing title of "Oceanographer of the Navy" to mention only a few highlights of great activity.

Much of the attention in recent years has been in the "use" of the seas. The excellent report: "Effective use of the Sea" prepared by the President's Science Advisory Committee, provided a splendid review. We, at Woods Hole, can be proud that our work over 36 years has been instrumental in laying the ground work for the opening of man's largest frontier on earth.

But, we should not let up, rather increase our efforts to acquaint the public (whose money we use) with general oceanographic research. The hefty two volume "1965 Collected Reprints", recently published by the Institution, provides an impressive example of the exciting and diverse work pursued by our scientists.



# Volcanic



"After some hours we came in sight of a solitary rock in the ocean, forming a mighty vault, through which the foaming waves poured with intense fury. The islets of Westman appeared to leap from the ocean, being so low in the water as scarcely to be seen until you were right upon them. From that moment the schooner was steered to the westward in order to round Cape Reykjaness, the western point of Iceland."

From: Jules Verne: "A Journey to the Center of the Earth."

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# Electricity

## *THE SIGHT AND SOUNDS OF A NEWBORN ISLAND RE-ENACT THE DISTANT PAST OF OUR GLOBE*

by D. C. BLANCHARD

### **The Birth of Surtsey**

**I**T is unlikely that even the imagination of Jules Verne could have foreseen that some day the Westman islands, about ten kilometers off the southern shore of Iceland, would be witness to a real-world spectacle to rival any of the fictional ones which flowed from his pen. When he wrote, "The islets of Westman appeared to leap from the ocean . . ." he was only using a delightful metaphor to indicate the smallness of the islands. But the passage of years has turned that metaphor into a fact. An islet of Westman has indeed leaped from the ocean.

On the 14th of November 1963, without preliminary rumblings, a volcano suddenly burst through the surface of the sea a few miles west of the southern-most of the Westman islands. Surtsey, a new islet, had been born.

For many days, it had been building itself up unseen from the floor of the ocean, about 130 meters below, and now finally thrust itself into the air. The sea poured into a large fissure and probably struck the molten lava. Explosions shook the new volcano. Fountains of ash and cloud rocketed skyward. The island grew rapidly under a rain of ash; three months later, in February of 1964, it was a mountainous pile about 170 meters high and nearly 1000 meters across.

JÖNASSON

## **Electrical Activity**

During these months the ejection plumes and the volcanic clouds were occasionally ablaze with numerous short, zig-zag flashes of lightning. As this electrical activity is of great interest to several of us in the United States, a trip to the volcano was planned. We hoped to get some clues as to how electrical charge is generated in certain volcanic eruptions and what role is played by sea water. And perhaps some of the knowledge obtained about volcanic cloud electricity would be applicable to the still unsolved problem of thunderstorm electricity.

We went to the Westman islands in Iceland and rented a local fishing boat. After instruments were put aboard to measure the atmospheric potential gradient and the corona current (the latter from a sharp point atop the mast) we steamed out to Surtsey. I wrote a brief account of the trip for "Oceanus", Vol. X, No. 4,\* but as the data had not been reduced, I did not dwell on our preliminary findings. Now, over two years later, after more laboratory and field work, some conclusions concerning the electrical activity have been reached. But first let me describe the scene when we neared the islet in February 1964.

At times Surtsey was quiet for many minutes and the bottom of the crater filled completely with sea water. Sea birds swooped low over the quiet surface. Suddenly the volcano would awaken, the water in the center of the crater began to bubble, and, within a second or two, ash and cloud hurled upward and outward at initial speeds of up to 100 meters per second (about 220 mph). Like a huge black and white balloon being inflated, the outpouring swelled quickly until its top had reached a height of over 700 meters. From the surface of these clouds secondary explosions hurled huge feathered spears of cloud and ash that fanned outward and finally arched down in long exquisite streamers silhouetted against the clear blue sky.

## **Thunder & Lightning**

Lightning and thunder occurred during all these eruptions, but most exciting to us was the trace drawn on the chart by the pens recording the potential gradient. At the start of an eruption, the surface potential gradient was not much more than +100 volts per meter, a normal value to find at sea. (The sea is defined as being at zero potential. The potential of the fair weather atmosphere increases



The antenna used to measure the atmospheric potential gradient on the chartered fishing boat 'Haraldur'.

BLANCHARD

\*See also: "Lava and the Sea" by A. H. Woodcock, Oceanus, Vol. VI, No. 3, March 1960.



From the hot lava fountain at right, the lava flows around the peak of Surtsey into the ocean at left, producing a positively charged cloud.

with height, initially at a rate of about +100 volts per meter of altitude.) But as the clouds billowed upward, the gradient rose rapidly to several thousand volts per meter. And then, simultaneous with a lightning stroke, the gradient would fall back to nearly 100 volts per meter. This reversal occurred repeatedly, and the pen traced a sawtooth curve.

### Positive Charge

With this data, and knowing the size of the cloud and our position with respect to it, we were able to deduce that the rising clouds were highly charged with positive electricity. As they issued from the orifice of the crater, the concentration of charge was estimated to be of the order of +100,000 to +1,000,000 elementary charges per cubic centimeter (an elementary charge is the charge carried by an electron). The total charge flow per second constituted a positive current of about 0.03 ampere. Though only about three per cent of the approximately one ampere current generated in a thunderstorm, this was sufficient to produce the electrical effects we observed.

The source of the positive charge is

still unknown, although there is the possibility that it could have been generated by sea water striking the molten lava in the crater. This effect can be demonstrated in the laboratory by letting drops of sea water fall onto molten lava. Small explosions occur, and the sea water is quickly converted into a positively charged cloud that contains numerous tiny drops of sea water or sea-salt particles. The equal and opposite negative charge is given to the lava.

Although it is tempting to attribute to this mechanism the intense charge generation which we observed at Surtsey, the fact is that conditions in the throat of an erupting volcano are exceedingly complex. For example, can we even be certain that behind that wall of cloud and ash we saw at Surtsey, sea water was striking the molten lava? It appeared to be but maybe it was vaporized in the intense heat within the throat. And how about the ash—did it carry negative charge into the air? Questions like these must be answered before we can conclude definitely, that Surtsey's electricity was the direct result of sea water striking hot lava.

## Flow of Lava to the Sea

A conclusive proof of the capacity of sea water to generate charge upon striking hot lava probably could be obtained by making potential gradient measurements near the clouds that are produced when molten lava flows into the sea. There would be no denying that the sea water struck the lava, and the clouds would contain little or no ash.

The conditions for this experiment were set up on the 4th of April 1964 when the opening to the sea in Surtsey's crater became blocked with ash. The sea water could not gain entry, the great explosions stopped, and a molten lava lake formed. Fountains of molten lava sprayed over 30 meters into the air. Later the same day the lake overflowed, and small streams of lava made their way down the sides of the crater and into the sea. Dense plumes of white cloud rose up and were carried off by the wind.

On the 24th of July, S. Björnsson, one of the Icelandic scientists who had worked with us on the Surtsey expedition, sailed around the volcano aboard an Icelandic Coast Guard ship which was equipped to measure the potential gradient. Molten lava was flowing down by the main peak of Surtsey into the sea. The cloud plume arising from the water was carried by the wind over the western edge of the island and out to sea. Bjornsson had the ship sail around the island and directly toward this cloud plume. The potential gradient had been about normal, but as the ship approached the plume, the gradient began to rise, slowly at first, but then very rapidly, until it reached a maximum of about +3200 volts per meter under the plume.

There was no doubt about it this time. The long horizontal line of cloud carried a positive charge that must have originated back at the source of the cloud: the splashing of the sea against the molten lava. As the cloud rose, the concentration of positive charge, according to calculations that were made later, was at least one million elementary charges per cubic centimeter. This agreed very well with the laboratory work carried out at Woods Hole. Though the lava—sea water charge generation mechanism is beyond a doubt, the basic physics behind it still is not clear.

**DR. BLANCHARD** is an Associate Scientist in our Department of Meteorology, and is interested in general problems of atmospheric physics. He has finished a book "From Raindrops to Volcanoes" to be published by Doubleday in the Anchor Science study series.

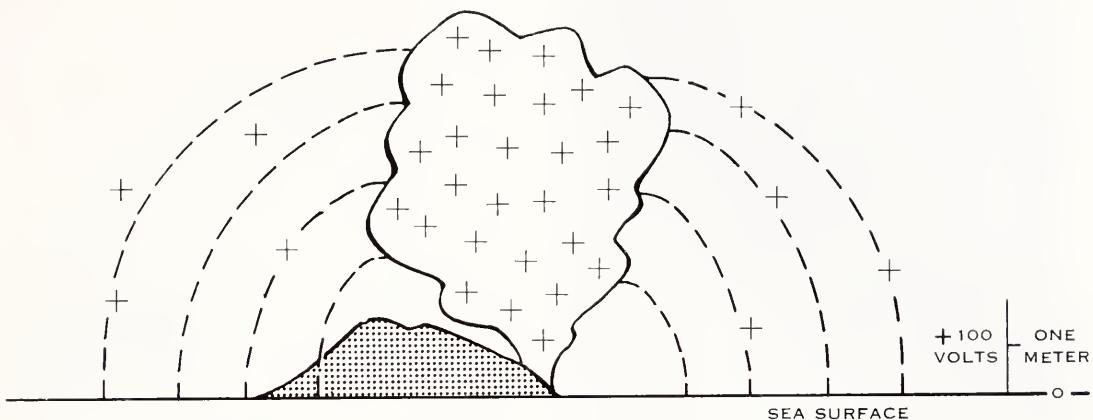
Björnsson made two other visits with a helicopter which landed him directly on the island. He was able to carry his potential gradient meter up to the very edge of glowing streams of liquid lava, and into the dense white clouds that were generated in great profusion as the lava was quenched by waves along the shore. His findings were the same; the clouds that rose from the sea were highly charged with positive electricity. Negative electricity was never found.

Although Björnsson has shown clearly that positively charged clouds can be produced when the sea makes contact with molten lava, the question of the source of the positive charge that we observed during the violent eruptions of



JOHNSON

The author, right, with Mr. C. Moore, then with A. D. Little, Inc. observe the birth of Surtsey.



The positive charge density in the volcano cloud far exceeded that normally found in the atmosphere. The dashed lines show the direction of the potential gradient caused by the charged cloud. The strength of this gradient (a measure of the charge density in the cloud) was measured with the antenna system aboard the 'Haraldur'.

Surtsey must remain open. Admittedly, Björnsson's work makes it seem probable that sea water also was the cause of the positive charge, but there remains an element of doubt.

### The Future of Surtsey

In late May of 1965, after a year and a half of activity, Surtsey became quiet. The powerful forces which had created the island looked for another outlet, and in early June the sea began to boil about 1300 meters northeast of Surtsey. The familiar fountains of ash and cloud rocketed skyward and Syrtlingur was born.

On the 24th of October Syrtlingur was about 500 meters in diameter and 50 meters high, but then it, too, became quiet. A week later, under the ceaseless pounding of the ocean waves, its slopes of ash were eaten away and it disappeared into the sea. Surtsey had been spared that fate because nearly half of it was covered by a protective armor of hardened lava.

More activity was to come. The day after Christmas the eruptions started again, this time about 1600 meters to the southwest of Surtsey. Heavy winter storms prevented Christmas Island from growing very rapidly, but it continued in eruption until August 1966. Then, like Syrtlingur, it disappeared into the sea.

A week after the eruptions stopped on Christmas Island a fissure opened on the southeast coast of Surtsey. The island

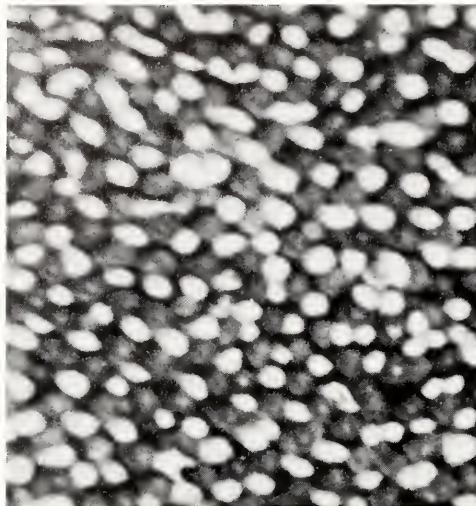
came to life once again as fountains of lava played from four craters to heights of about 150 meters.

Man has learned much from Surtsey and its eruptions. The new knowledge extends far beyond what we learned in our study of the electricity in the volcanic clouds. Many other scientists have visited Surtsey; their interests have ranged from chemical changes in the sea to biological studies of life on the new volcanic soil.

A number of research trails have met and are crossing at Surtsey, and those of us involved would be foolish indeed if we did not take cognizance of this fact. At one of these junctures a new and exciting research trail may have been found. The signpost pointing the way does not say: volcanic electricity, types of lava, fissure eruptions in the sea, heat flow through volcanic ash, or sea water and electricity. It says, "A key to the past."

The birth of Surtsey and the formation of the volcanic clouds, the struggle with the sea and the coming of life to the new island, are a re-enactment of what has happened hundreds of times in the distant past. In this event, capsule in space and time, may be a key that will enable man to open yet another door that obscures our view down that long corridor through which he and the world have travelled.

A book with interesting text and beautiful color photographs is: "Surtsey, the New Island in the North Atlantic" by Sigurdur Thorarinsson. Almenna Bokafelagid, Reykjavik, Iceland.



Intimate contact between the arteries (white) and veins (black) are shown in this enlarged section of tuna blood vessels. A cubic centimeter of this mass of vessels contains more than 100 square centimeters of walls, half arteries and half veins. Such a large area facilitates heat exchange.

IN 1816 a curious British physician, John Davey, sailed on a ship in the tropics and measured the temperature of some skipjack. He found that the muscles of the fish were  $37.4^{\circ}\text{C}$ . or  $10^{\circ}$  higher than the surrounding seawater. Since then many more temperature measurements have been made and have shown that most fishes are within one degree of the water temperature. Tuna, however, commonly are found to be considerably warmer than their habitat.

There are many advantages to being warm. Digestion, the speed of nerve impulse transmission, and metabolic reactions in general speed up. The rates of enzymatic reactions increase two to four-fold with each  $10^{\circ}$  rise in temperature. Muscle contraction and relaxation will be three times faster while the force of each contraction will remain the same. Thus, the fish can obtain three times as much power from the same mass of muscles by increasing its temperature  $10^{\circ}\text{C}$ . Tuna have been clocked at 70 kilometers per hour for a 10-20 second sprint\*, a greater speed than any other marine animal. Speed is proportional to the ratio of power over drag. A look at a tuna shows that it is an extremely streamlined animal and it is unlikely that drag could be further reduced. Therefore, they probably owe their great speed to the extra power available from their warm muscles.

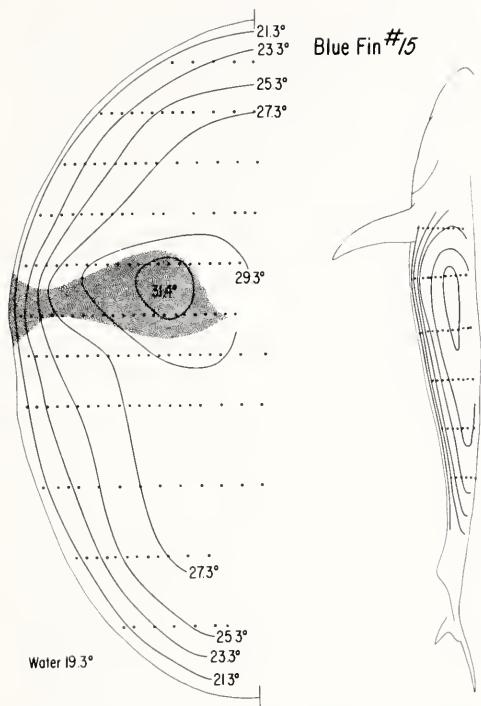
# Why is a Tuna Warm?

by F. G. CAREY and J. M. TEAL

Marine mammals have a temperature of about  $37^{\circ}\text{C}$ . even though many of them live in the frigid waters of the Arctic and the Antarctic. At first glance, therefore, it may not seem too surprising that tuna fish are about  $10^{\circ}$  warmer than the water. But mammals breathe air and it takes little heat to warm a lung full of air from environmental to body temperature. The heat capacity of water, however, is three thousand times as great as an equal volume of air. Also the amount of oxygen dissolved in water is low and a fish must process 40 volumes of water to obtain the amount of oxygen present in one volume of air. The result is that cooling during respiration is 100,000 times as great for a water breathing animal as for an air breathing animal.

On leaving the heart, all of a fishes' blood passes through the gills where it is cooled before reaching the tissues. The blood is in the gills long enough to equilibrate with the oxygen dissolved in the water. Since heat diffuses ten times as rapidly as oxygen, the blood in the gills is cooled to the surrounding water temperature before passing into the body to bathe the tissues. While the marine mammal solves part of his heat problem by sufficient insulation (such as the blubber of a whale), the warm bodied fish has a much more severe problem of coping with the refrigerating powers of its blood.

\*V. Walters. *Nature*, 1965.



Pattern in temperature distribution in a tuna.  
The warmest region lies in the dark muscle  
near the widest part of the body.

**DR. CAREY and DR. TEAL**, scientists in the Biology Department of the Institution, are interested in the physiology of marine organisms. In the pursuit of their work they have been known to use some strange home-made "research vessels".

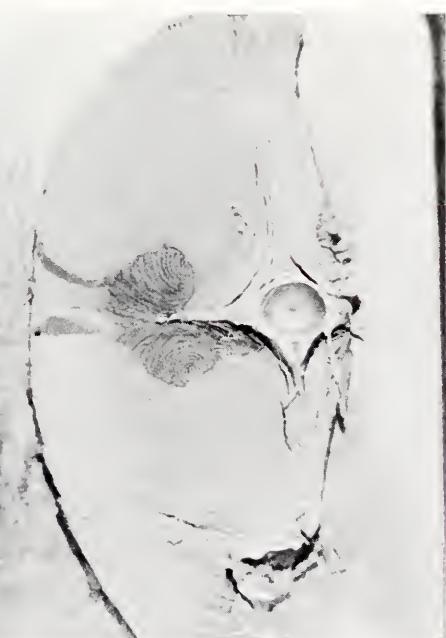
### Metabolic heat

In both mammals and fish the source of body heat is the same; the combination of food stuffs with oxygen releases chemical and mechanical energy which appears as heat. The rate at which this metabolic heat is produced is proportional to the oxygen supply which in turn is proportional to the flow of blood through the tissues. Since metabolic heat is lost as rapidly as it is produced, it is apparent that metabolism can cause little rise in temperature above that of the environment.

As an example on how this works, we can calculate the maximum steady state temperature of a tuna. Tuna blood may hold 0.15 to 0.20 volumes of oxygen per volume of blood. The heat released by the combination of this much oxygen with metabolites in the body would be about 0.8 small calories for the oxygen carried by one milliliter of blood. This is enough to raise the temperature of the milliliter of blood 0.8°C, but this heat is lost to the water on the next passage through the gills. No heat accumulates in the body and the temperature elevation is 0.8°C. Since most fish have a considerably lower blood oxygen capacity, they would be expected to have correspondingly lower temperatures. Despite this apparent limitation, tuna are often found to have temperatures ten or more degrees above that of the sea. Obviously something else is involved.

We believe that to raise the temperature it is necessary to conserve the metabolic heat and prevent its loss to the water in the gills. A thermal barrier must exist in the circulation between the tissues and the gills which allows the passage of blood, but stops the passage of heat. A variety of animals have been found to have systems capable of acting as such thermal barriers.\* The mechanism lies in a common feature of vertebrate circula-

GAREY, FROM A KODACHROME



A steak cut from a blue-fin tuna for comparison with the temperature distribution, shown above. The dark and light muscle are clearly shown, as well as the retia leading from the blood vessels near the skin toward the dark muscle.

\*See "How cold is a whale's tail?", *Oceanus*, Vol. V, Nos. 1 & 2.

## Tuna

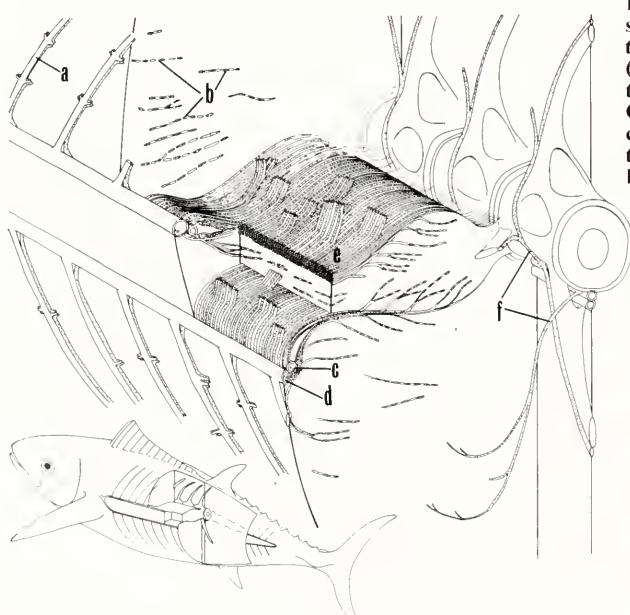
tory systems: arteries and veins typically follow the same paths and often lie side by side in actual contact. The blood flows in opposite directions in arteries and veins. If there is a difference in temperature between arterial and venous blood, and the vessels are in contact, some heat will flow from the warmer to the cooler vessel and be carried back in the direction from which it came. This constitutes a thermal short circuit which impedes the flow of heat along the vessel. Many animals have developed this system into a heat conserving mechanism, known to engineers as counter-current heat exchangers. A crude system of this type is found in the human arm where the venae comitantes lie close to the brachial artery. When the arm is cold an appreciable amount of heat can be transferred from the arterial to the venous blood. This pre-warming of the venous blood returning from the cold arm facilitates control of our deep body temperature. Other animals such as sloths and lemurs, whales and porpoises have more highly developed systems which function much more efficiently to transfer heat from arterial to venous blood. Such masses of parallel small blood vessels were called rete mirabile or "miraculous net" by early anatomists. This is the type of thermal barrier needed in the circulation of the

tuna. It would retain the metabolic heat in the tissues by transferring it from the outgoing to the incoming blood stream.

### Intricate net

Tuna do have highly developed rete mirabile in the circulation to the viscera and muscles. The main blood supply to the muscles is through a system of large blood vessels located on the sides of the fish just under the skin. From these large blood vessels and running into the muscle are masses of parallel arteries and veins. These rete mirabile are located at the upper and lower margins of the dark muscle and extend along most of the length of the fish. The lighter colored muscle above and below the main rete is served by branches from it and through the segmental vessels as shown in the illustration on this page. Branches from the vessels which run vertically just under the skin give off smaller branches which penetrate into the muscle. These smaller branches are sheets of arteries and veins in an alternating array which we call vascular bands.

We went out last winter to study live tuna caught on a long line cruise of the U.S. Fish and Wildlife Service and later made observations on tuna taken in fish traps off nearby Provincetown. The cap-



Rete mirabile of the muscle (e) showing how they originate from the cutaneous artery (c) and vein (d) and run into the body along the margins of the dark muscle. Other regions are supplied by vascular bands (b) which arise from the segmental vessels (a) and by branches from the dorsal aorta (f).



tured fish were given an intravenous injection of curare which immobilized them within a minute or two. The drugged fish then was placed in a rack and we stuck a hose in its mouth. A large volume of water was run through the gills to allow the fish to breathe and a second hose kept the skin of the fish wet and at water temperature. Under these conditions the tuna remained alive and had a strong heart beat for hours.

We measured the temperature of the muscle with thermistors in the tips of long hypodermic needles. Many temperature measurements were made in various regions of the fish. When the data were plotted, we obtained an idea of the temperature distribution within the muscle. A hot spot is found in the dark muscle. This is surrounded by a region of high temperature in the light muscle which decreases with a sharp gradient to water temperature at the skin. We related the observed temperatures to the circulation as follows. The blood entering the muscles in the cutaneous arteries came directly from the gills and was at water temperature. The blood in the muscle was at tissue temperature, or  $10^{\circ}\text{C}$  above the water but on leaving the muscle in the cutaneous vein its temperature had dropped to within  $0.1^{\circ}$  or  $0.2^{\circ}\text{C}$  of the water. This meant that the outgoing blood had transferred 98% of its metabolic heat to the incoming blood. The incoming blood was warmed and thus would not cool the muscle, the outgoing blood was cooled almost to water temperature and would lose little heat to the water in the gills. The maximum temperatures were found in the dark muscle at the inboard end of the main rete; lower temperatures were found in regions supplied through branches from the main rete or through the vascular bands. Thus the temperature of an area was related to the complexity and heat exchange ability of the rete serving it. As an example of this, note that the center of the fish, near the vertebra was not the warmest region. This region was supplied by branches from the dorsal aorta which runs just beneath the vertebra. These branches were simple vas-

cular bands and would have low efficiency as heat exchangers.

Recall that the main blood flow in the rete and vascular bands was from the cutaneous vessels inward. This locates the cold end of the heat exchanger on the outside of the fish and the warm end in its interior. As a result, the surface of the fish is cool, the gradient between water and skin is low and heat loss from the surface of the fish is reduced.

#### Other fish

As we pointed out there are advantages to having a warmer temperature than the environment. Then why are other fast swimming fishes not warmer than the water? We have measured the temperature of swordfish, dolphin fish, flying fish, barracuda, silky shark, mackerel, spanish mackerel and blue and rainbow runners. All of these were within a degree of water temperature. Other investigators have had similar results with these and other fish. Care must be taken in making the observations as the fish pick up heat rapidly from hot decks or the sun. Small fish in particular will change their temperature quite quickly. There are a few measurements which seem to indicate that the blue marlin may have a temperature several degrees above the water. We hope to look into this further.

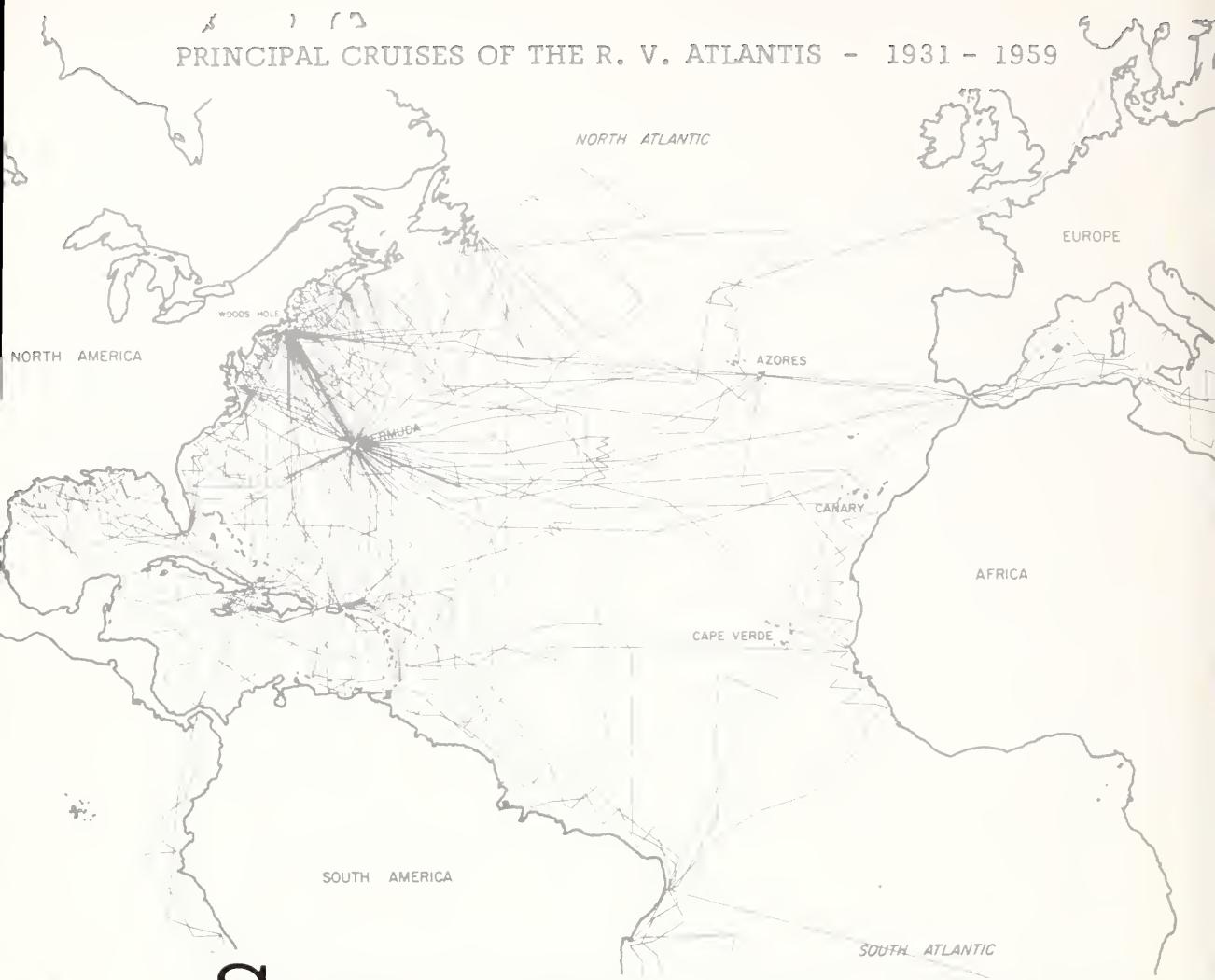
The mako shark, however, does have a high temperature. We measured muscle temperature of  $26^{\circ}\text{C}$ . in sharks from  $20^{\circ}$  water. The mako has the same structures in its circulation as the tuna. The temperature patterns also are quite similar with the warmest area in the dark muscle at the end of the large rete and a sharp decrease to water temperature at the skin. There are two other sharks in this group, the porbeagle and the great white shark, (*Carcharodon carcharias*). These too have similar structures in their circulation and we hope to have an opportunity to measure their temperatures soon.

We find it most interesting that these fast fish, the isurid sharks and tuna, have evolved such nearly identical systems for maintaining their bodies above water temperature. The fish are not at all related. Apparently this is a case of parallel evolution.

**The authors at work on a mako shark in a trough on board the R.V. 'Anton Bruun'. Note the water hose in the shark's mouth and the water streaming out through the gills.**



8 113  
PRINCIPAL CRUISES OF THE R. V. ATLANTIS - 1931 - 1959



## SOME LITTLE KNOWN SAIL





## VIEWS OF THE 'ATLANTIS'





## Is "long lost Atlantis" no more lost?

Part of the collapsed volcanic cone as seen from Thira.

The island of Theresia is in the background.

At left is part of the active volcanic top

which is slowly rebuilding Santorini into the circular shape it had  
before the great explosion.



# Volcanoes and *History*

or

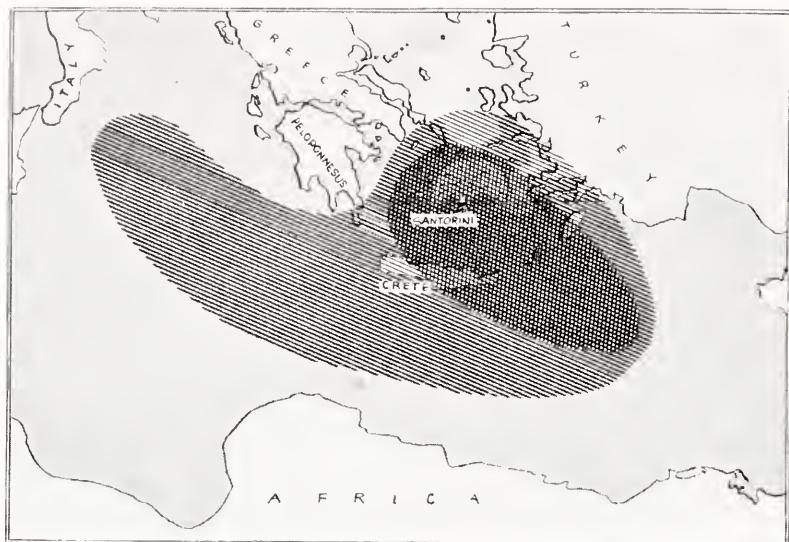
## "Atlantis" Revisited

by J. W. MAVOR, JR.

THE island of Thira, 100 kilometers north of Crete in the Aegean Sea erupted with tremendous violence between 1500 and 1450 B.C. At the end of this period a large part of the island collapsed into the sea creating enormous tidal waves which caused floods and coastal damage as far away as Egypt.\* The roar of the explosion may have been heard as far away as Scandinavia.

Standing on the edge of the collapsed volcanic cone (caldera) of Thira, a sheer drop 400 meters above the sea, one can see the surrounding islands of Anaphi, Amorgos, Sikinos, Ios, and Pholegandros and in the winter, Crete. The enormity of the cataclysm is brought home with frightening clarity. Around the rim of the caldera, some 10 kilometers in diameter, the 40 meter thick white volcanic ash layer of the Minoan eruption is visible, contrasting with the layers of black and red lava beneath.

\*See: "A mighty bronze-age explosion" by J. W. Mavor, Jr. Vol. XII, No. 3 Apr. 1966.



By permission of: Saturday Review

—Doug Anderson following Ninkovich-Heezen.

**Synopsis of the story of two explosions of the Santorini volcano.** First eruption occurred about 25,000 years ago, strewed ashes over the boomberg-shaped area shaded with slanted parallel lines in sketch above. Second eruption took place about 1400 B.C. Its ash deposits covered cross-hatched oval in the sketch. Note how second ash layer blanketed most of Crete, occupied at that time by beauty- and peace-loving Minoan people.

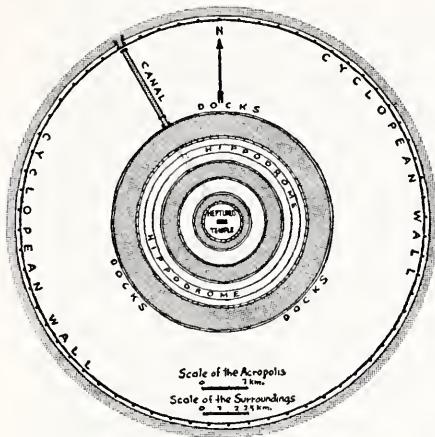
Professor A. G. Galanopoulos, who is director of the seismic laboratory at the University of Athens, proposed in 1960 that Thira was the metropolis of Plato's Atlantis, the smaller of two islands making up the royal lands. The other, the royal state, was Crete. Other settlements on the Aegean islands, and along the eastern Mediterranean coasts were ruled from these two islands. Galanopoulos has presented considerable evidence to support his theory. Moreover, Mellis, and Ninkovieh and Heezen have reported the analyses of deep sea cores which indicate the widespread effects of the great volcanic explosion.

The Minoan civilization in its palace period from 1900-1450 B.C. is known from excavations of the Cretan palaces. Written letters and artifacts of the surrounding cultures appear to relate to the Minoans and to the collapse of their civilization. The records include Plato's dialogues *Timaeus* and *Kritias*, the Tell-el-Amarna letters of Egypt, the excavations at Tell-el-Qedah in Palestine, the tradition of the flood of Deukalion, the Hittite legend of Ullikummi, and the Etrusean excavations in Italy. Also pertinent are the Old Testament books of Judges, Exodus, Amos, Jeremiah, Zephaniah, and Joshua, and the inscriptions

of Tel-el-Yahudiya. References in Egypt include the Hermitage papyrus, the Ipiwer papyrus, and the inscription at Speos Artemidos. J. G. Bennett has discussed the Egyptian sources showing that the Thira cataclysm was destructive in Egypt.

### Preliminary Survey

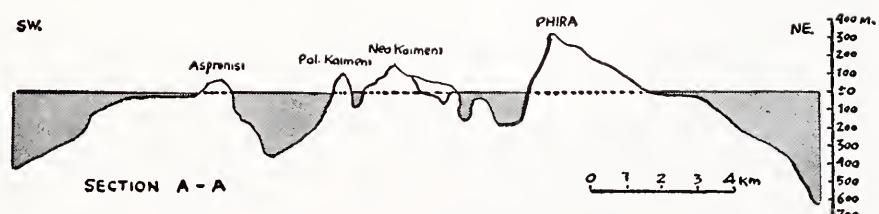
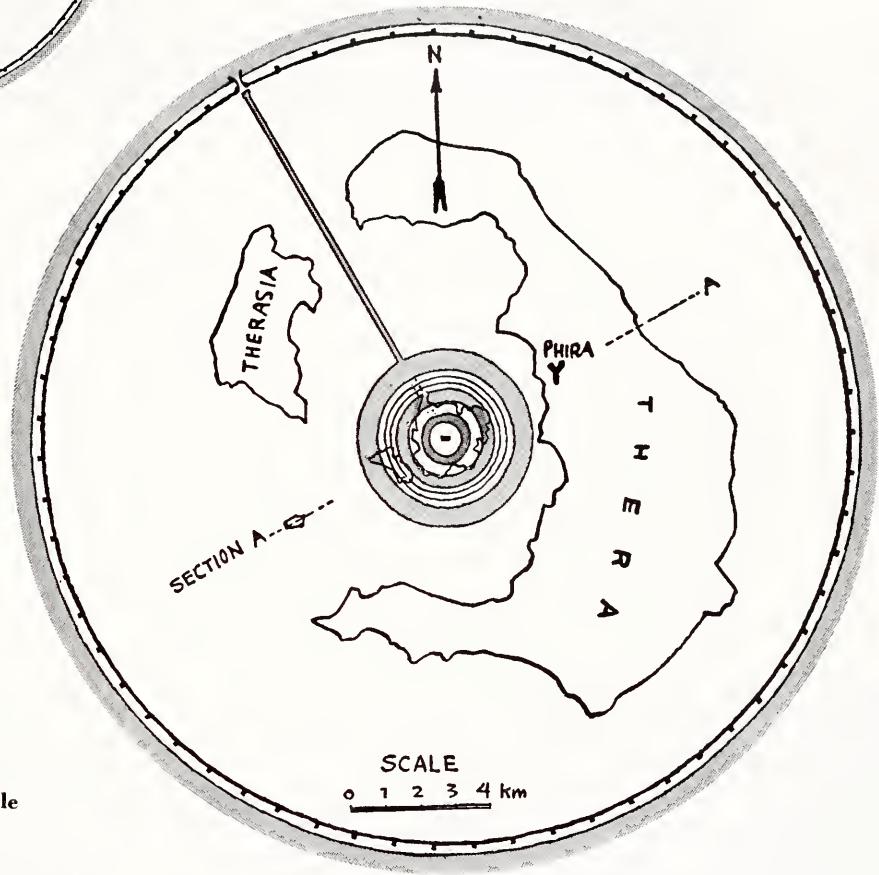
Late this summer, from August 26 through September 10, we made a preliminary survey to discover further evidence to support Professor Galanopoulos suggestions that Thira is the site of "long lost Atlantis." Two items of Plato's story were considered major areas of interest. 1. A comparison of the physical description of the island. 2. A search for remnants of the Atlantean civilization. Kritias described the metropolis of Atlantis as a circular island 100 or 105 stadia in diameter. Inside this circle were three naturally formed ring-shaped harbors with a connecting channel between and to the sea. White, black and red building blocks were said to be quarried from the raised banks of the harbors. On the center island, five stadia in diameter, was a hot spring and a cold spring. To verify this description, it is necessary to reconstruct the topography of the island prior to the collapse of 1450 B.C.



**Design of lost island  
of Atlantis,  
drawn to scale  
from description  
in text of Plato's dialogues,  
is reproduced  
immediately above.**

**At right, top, same design,  
also drawn to scale,  
is fitted over map  
of surviving remnants  
of Santorini volcano.**

**At right, below, vertical profile  
of Santorini remnants  
suggests presence of annular harbors  
described in Atlantis.**





**Around the rim of the caldera, the thick layer of white volcanic ash contrasts sharply with the layers of black and red lava.**

We were fortunate in that the R.V. 'Chain' was on a geophysical cruise in the eastern Mediterranean with Mr. E. F. K. Zarudski as Chief Scientist on board. Due to his interest in Thira our survey party was transported on the 'Chain' from Athens to the island. The ship then spent one day at Thira to make a seismic sparker profile\* through the caldera and around the island. Although we have to await complete analysis of the records the seismic profile indicated a radial cross section of the collapsed portion of the island underwater and a deep filled basin within the caldera which could have been a pre-eruption waterway. An examination of the cliff strata and underwater bottom profiles made by the survey party, using Professor Edgerton's short-ping sediment profiler, indicated a complex volcano having many lava plugs or tubes. It does not appear that the island was a single cone before the eruption but several intersecting cones. It may well have had a caldera of smaller size than the present one. The cyclic behavior of the volcanic activity (building up and collapsing) reported by Ninkovich and Heezen supports this thesis. The Minoan eruption of fine white ash does not appear to have come from a central single vent since it varies in both thickness and size over the island.

The present island group is smaller than the metropolis of Atlantis was reported to be. There is evidence that land slumping took place on the island periphery either during or after the eruption. The survey indicated a 2 to 4 kilometer larger pre-eruption outline which fits Plato's 100 stadia diameter exactly.

\*See: "The seismic profiler", Oceanus, Vol. VII, No. 4, June 1961.

Plato described a caldera with volcanic islands inside the collapsed cone. The lava, pumice, and tuff of Thira which are cut from the cliffs and used for building blocks are white, black and red. Hot springs occur on the central volcanic cone and a single cold spring occurs presently on the limestone mountain, Mt. Elias, a 600 meter sheer outcrop.

#### Search Evidence

The second major area of interest was the search for evidence that Thira was the religious center of the Minoan or Atlantean civilization and that temples and palaces are to be found. No evidence has yet been found of large Minoan temples. Certainly, any ruins on the central part of the collapsed island have been destroyed beyond recovery. In 1879, Fouque reported three excavations on separate parts of the island. A fourth was found by Galanopoulos in 1956. These ruins were all discovered at the bottom of the top white and rose pumice layers and were well preserved, buried as at Pompeii. Minoan artifacts including pottery, gold jewelry, copper tools, and skeletons were found. The habitations seemed to be farms. Most discoveries were made during mining operations when the pumice was dug from the cliffs and conveyed to ships for use in cement. The modern practice of blasting and bulldozing is constantly destroying Minoan ruins. In spite of this, wood and pottery were observed during the current survey in the

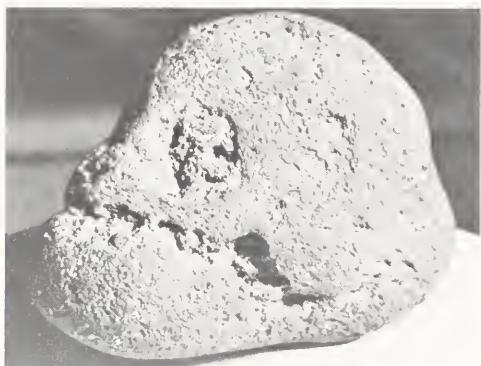
**MR. MAVOR** is a research specialist in our Department of Applied Oceanography. He took part in the development of our D.R.V. 'Alvin'.

## "Atlantis"

red weathered lava earth just under the rose pumice. Wood samples were taken for carbon 14 dating. In one pumice mine, evidence of a fresh water lake or marsh was found. From the thickness and composition of the earthy Minoan surface in two locations, it appears that there were wooded regions on the island. Plato mentions spring fed ponds and excellent soil.

### Fossil monkey

Previous to the present survey, E. Loring found a fossil monkey head on



A. G. GALANOPPOULOS

the beach at Kamari. This fossil found in the pumice and lava formed during the eruption of Thira was inspected by Professor Poulianou, a leading anthropologist, who identified it as Cercopithecus Callitrichus or West African Green Monkey. Such animals are known to have been brought to Crete by ship for the amusement of royalty. This implies the presence of royalty on the island and one might speculate that adequate quarters comparable to the Cretan palaces were available.

At the summit of Messavouno, a 350 meter high spur of Mt. Elias, lie the extensive ruins of ancient Thira, settled since Phoenician times in 1100 B.C. Each succeeding people rebuilt with the stones of the preceding culture, there being no sedimentation to establish the strata upon which archaeologists depend for relative dating. Inscriptions, architecture, and design are the guides here. On the site of this great ruin, all the white pumice layer has weathered away leaving bare limestone. While no Minoan antiquities have been found at this site, an

**A cold spring is found on Mount Elias. The monastery of the Prophet Elias is situated on top of the 600 meter outcrop.**



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## "Atlantis"

ancient Greek stone inscription reading ΕΥΜΝΑΩΣ exists. According to Plato, Ευμήλος which means "rich in sheep", was the twin brother of Atlas, King of the islands of Atlantis. Ευμήλος was given as his lot an island nearest the pillars of Herackles. Galanopoulos has suggested that the Egyptian manuscript of the story of Atlantis did not mention the pillars of Herackles and that this place known as the present day Strait of Gibraltar was an embellishment added by Plato. Plato was presented with a description of the geographical location of Atlantis which clearly places it in the Aegean Sea. However, he was faced with dimensions far too large to place it in the Mediterranean. Furthermore, he did not know of the eruption of Thira. Faced with this dilemma and being a logical person, he placed Atlantis in the Ocean Stream beyond Gibraltar. The name Atlantis in its Greek meaning, daughter of Atlas, may have been part of the original story or it may have been invented by Plato. The narrow passage identified by Plato as Gibraltar was more likely one of the many straits in the Aegean such as Dhiavlos Elafonison at the southeastern corner of the Peleponnesus. The island of Melos, West of Thira, may be the ancient domain of King Μῆλος. The location of Atlantis on the Mid-Atlantic ridge of the Atlantic Ocean, considered by many people as the most likely location, is based solely on a few brief sentences of Plato whereas an Eastern Mediterranean location is clearly indicated by many other parts of the text. Radio-isotope measurements of sediment of the Mid-Atlantic Ridge suggest no major changes for the past 73,000 years. Geophysical studies in the central Atlantic Ocean Basin indicated no major changes over a period of 280,000 years.

### Factor of 10

One of the more significant pieces of evidence supporting the Minoan-Atlantis theory concerns the numbers used in Plato's story. Atlantis is clearly said to be a bronze age civilization. The bronze age in Europe and the near East is dated from 2000 to 1000 B.C. Plato dates the destruction of Atlantis at 9000 years before the time of Solon in 590 B.C. Plato certainly did not describe a mesolithic culture, as

this date implies, so there must be an error. Let us assume that there is a factor of 10 error in the date, that in translation or recording, 100 was read as 1000. Such an error is easily made. The date of the destruction then comes out 1490 B.C. To make this more believable, there must be a consistent error throughout Plato's story and a substantial number of instances. This is the case. The royal state is described as an oblong region 3000 by 2000 stadia. Reducing this to 300 by 200 is just the size of the Neogene basin of Crete which is described perfectly in other terms. Moreover, a ditch or river is described surrounding the plain, 10,000 stadia long. This would be 1100 miles. The periphery of the plain of Messara in Crete is about 110 miles. The royal state is presented as one of the 10 kingdoms of Atlantis, the others being possibly in Libya, Tyrrhenia, etc. The army of this kingdom is organized in relation to each lot of land, about one square mile, furnishing so many chariots, archers, javelin throwers, etc. The number of lots is given as 60,000 and when reduced to 6,000 results in a more reasonable number of soldiers which probably still is exaggerated. The navy of 1200 ships is said to require 200 sailors per ship. From "frying pan" drawings, seals, and wreck excavation, we know that a typical Minoan vessel did not require a complement of over thirty men.

### Exaggerations

In picturing the cultures of prehistoric times, it is important to scale down one's impression from the inevitable exaggerations that occur in historical reporting. The people of Minoan times may have been less in number than today's population even though the land was more fertile. The geographical extent of Athens proper is given precisely and covers a small portion of Attica. The army was said to be drawn from the surrounding people. The war between Athens and Atlantis, won by Athens, was most likely a land engagement which took place on the shores of Attica. In the opening paragraph of this article it was said, referring to the Athenians, that "all your warlike men in a body sank into the earth". This was likely an earthquake associated with the collapse of Thira. Professor Galanopoulos



MAVOR

Digging into a Minoan surface below the 40 meter thick volcanic ash layer.

Professor  
A. G. Galanopoulos  
at Thira



On top of Mount Messavounos, a small dwelling was built partially with ancient stones found on Thira.



MICABE

## "Atlantis"

has shown by studying seismic records that Attica has not been subject to large seismological disturbances in historical times. Only the earthquakes and floods accompanying the collapse of Thira would create such an opening of the earth. Plato also reported that the Acropolis in Athens had a fountain spring which was extinguished by the earthquake. Evidence of such a spring has been found.

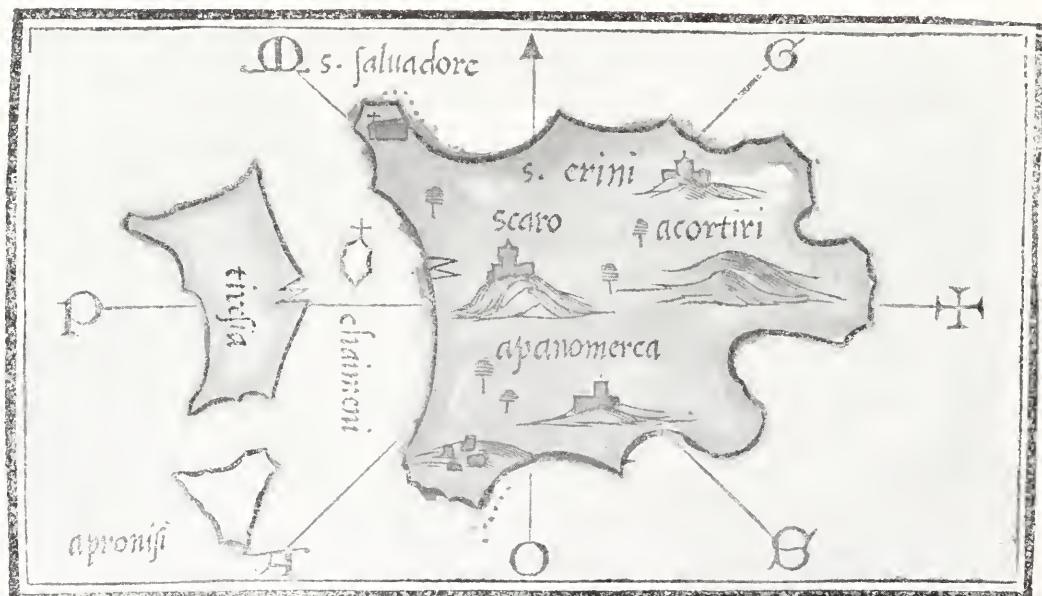
### Active digs

Active Minoan digs are currently underway on the island of Zea near Attica and at two recently discovered palaces on Crete, Zakros and Arkhanes. It is hoped that Thira can be added to this list in the near future. Needless to say, we are anxious to return.

A word should be said about possible underwater ruins at Thira. Several sites

have been reported. They were examined acoustically and where the water depth permitted, by swimmers. No diving equipment was used. On the caldera rim the bottom is very rough, covered with large rocks and deeply faulted. At three locations, formations which appeared man-made from surface, looked natural on close inspection. Off the southern and eastern beaches a stratum 2-6 meters under the sand was found which became irregular near shore. This could be a ruin or a naturally formed concrete geologically known as beachrock, which was found above the bottom in some places. Our conclusion is that the work should be pursued with more powerful equipment and facilities for diving. Both in archaeological and geological points of view, Thira would be a most interesting place for a deep submersible capable of working to a depth of 700 meters.

*The 1966 survey in and around Thira was privately financed. Among those taking part in the work were: Prof. A. G. Galanopoulos, Seismologist of the University of Athens; Prof. H. E. Edgerton, M.I.T.; Dr. H. Haskins, Council of Underwater Archeology; Mr. E. Loring, Historian; D. Davidsen and R. Yorke of Cambridge University.*



## Santorini

As depicted in a woodcut published in 1517 A.D. (From the collection of Robert A. McAbe)



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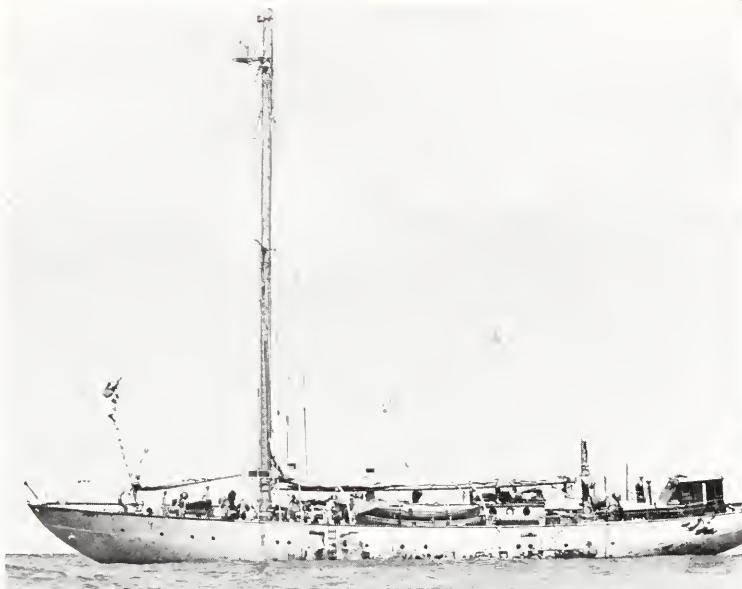
Although an active volcanic eruption or an earthquake always is possible, life goes on in the villages built on the steep slopes. The last earthquake in 1956 took a great toll in life and collapsed many buildings.



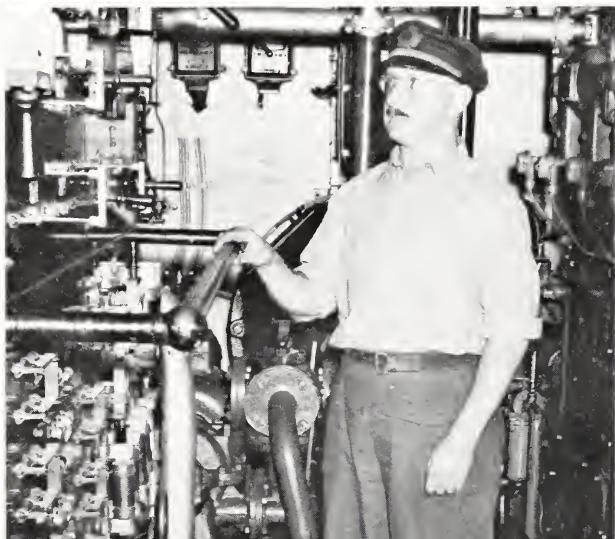
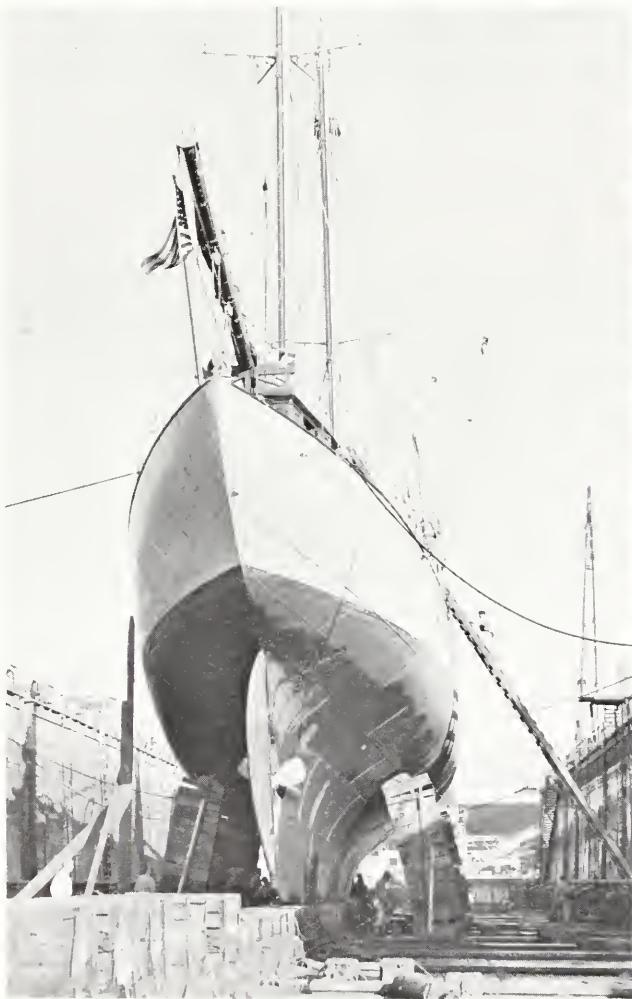
MCAE

... and sometimes,

MIC THAYER



she had a little trouble!



(BUT THE ENGINES ALWAYS WORKED!)



# Associates' News

## Louis E. Marron

**W**E announce with deep regret the sudden death of Mr. Louis E. Marron on September sixteenth. One of the world's better-known big game fishermen, Mr. Marron gave the Institution strong support during his twelve years as an Associate. He was vitally interested in the Fish Tagging Program and his contributions to the Institution included financial help, fishing equipment and the 'Eugenie VIII,' one of the finest sport fishing craft ever designed, the result of his thirty years of fishing experience. He is sadly missed by his many friends at Woods Hole and in fishing circles throughout the Western Hemisphere.

\* \* \*

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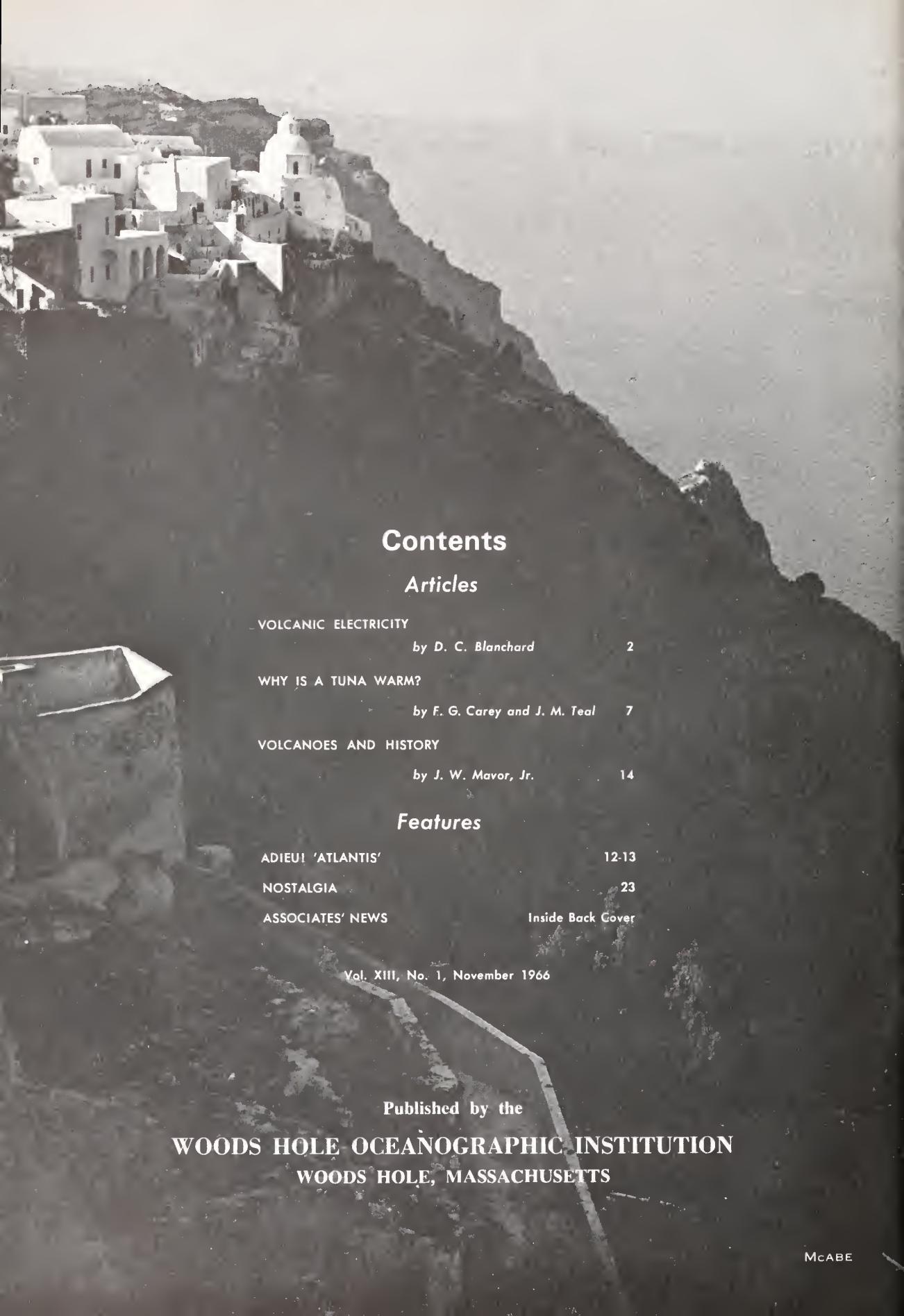
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